GE Nuclear Energy

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Class I

APPLICATION OF THE "REGIONAL EXCLUSION WITH FLOW-BIASED APRM NEUTRON FLUX SCRAM" STABILITY SOLUTION (OPTION I-D) TO THE MONTICELLO NUCLEAR GENERATING PLANT

Licensing Topical Report

February 1996

Prepared for Northern States Power Company by

GE Nuclear Energy

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Approved by: Jason Post

Jason Post,
Technical Services

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ABSTRACT

This report demonstrates the application of the "Regional Exclusion with Flow-Biased APRM Neutron Flux Scram" Stability Solution (Option I-D) of the "BWR Owners' Group Stability Long-term Solutions Licensing Methodology" to the Cycle 18 as-loaded-core of the Monticello Nuclear Generating Plant, in compliance with General Design Criterion 12. The analysis contained in this report has been performed based on power rerate conditions (1775 MWt) and bounds operation prior to rerate at 1670 MWt. An Exclusion Region is presented for the plant which identifies plant conditions that may lead to an instability. The Exclusion Region analysis shows that the large single-phase pressure drops induced by the relatively small inlet orifices of Monticello creates a preference for core-wide mode oscillations should the plant maneuver into the conditions susceptible to a reactor instability. The Exclusion Region analysis concludes that regional mode oscillations are not anticipated to occur for Monticello. In addition, a statistically based Detect and Suppress analysis is performed to demonstrate protection of the fuel Minimum Critical Power Ratio (MCPR) Safety Limit from the flow-biased APRM neutron flux trip. The Detect and Suppress analysis is performed for core-wide mode oscillations only, consistent with the Detect and Suppress licensing methodology documented to the NRC in NEDO-32465, May 1995.

1 INTRODUCTION

This report demonstrates the application of the "Regional Exclusion with Flow-Biased APRM Neutron Flux Scram" Stability Solution (Option I-D) to the Monticello Nuclear Generating Plant as prescribed by the BWR Owners' Group Long-term Stability Solutions Licensing Methodology[1,2]. This solution creates an "Exclusion Region" in the plant operating map wherein oscillatory power behavior is conservatively predicted to be possible and which is avoided during plant operations. The Exclusion Region analysis also confirms that core-wide reactor instability is the predominate mode and regional mode oscillations are not expected to occur for Monticello. The protection of the Safety Limit Minimum Critical Power Ratio (SLMCPR) afforded by the flow-biased Average Power Range Monitor (APRM) neutron flux trip is demonstrated for the preferred core-wide mode of coupled thermal-hydraulic/neutronic oscillations for Monticello.

1.1 Historical Perspective

Protection against power oscillations that might lead to fuel damage has been required by General Design Criterion 12[3], which requires that such oscillations either not be possible or be reliably detected and suppressed. In the past, this requirement was met by showing that oscillations are not possible by calculating core and channel decay ratios as a part of reload licensing analyses. Such results notwithstanding, guidance was provided to BWR operators as early as 1982 in the form of a GE Service Information Letter[4] on the detection and suppression of hypothetical power oscillations at low-flow and high-power conditions.

With the advent of 8X8 fuel designs and more aggressive operating strategies to improve operational flexibility and fuel utilization (e.g., extended load lines, feedwater heaters out-of-service, etc.), stability margins decreased such that instabilities could no longer be demonstrated to be impossible; therefore, in 1982 and after, protection against power oscillations was ensured by providing plant operators with guidance on detecting and suppressing such oscillations[4,5]. In addition, analysis was performed to demonstrate that the occurrence of such oscillations did not challenge fuel thermal-mechanical limits[6,7].

Additional concerns about BWR stability were raised by the March 9, 1988, oscillation event at the LaSalle-2 plant, when investigations revealed that power oscillations could occur more rapidly than had been thought probable. Furthermore, new analyses predicted less margin to the SLMCPR than was previously shown[8]. This event led NRC to issue Bulletin 88-07[9], which requires BWR owners to indicate how they would guard against such events in the future.

1.2 BWR Owners' Group Response

In response to NRC Bulletin 88-07, the BWR Owners' Group, in conjunction with GE, implemented a program to develop a long-term solution to the stability issue. The BWROG approach, as well as interim protective guidelines, was accepted by the NRC in Supplement 1 to the aforementioned Bulletin[10]. The BWROG efforts led to generation of the "BWR Owners' Group Long-term Stability Solutions Licensing Methodology"[1] , which outlines several solution options. Some of these involve the introduction of a new Reactor Protection System (RPS) trip function and may be applied to all BWR's, while others demonstrate the adequacy of existing hardware but are applicable to only a limited set of plants.

1.3 Option I-D Solution

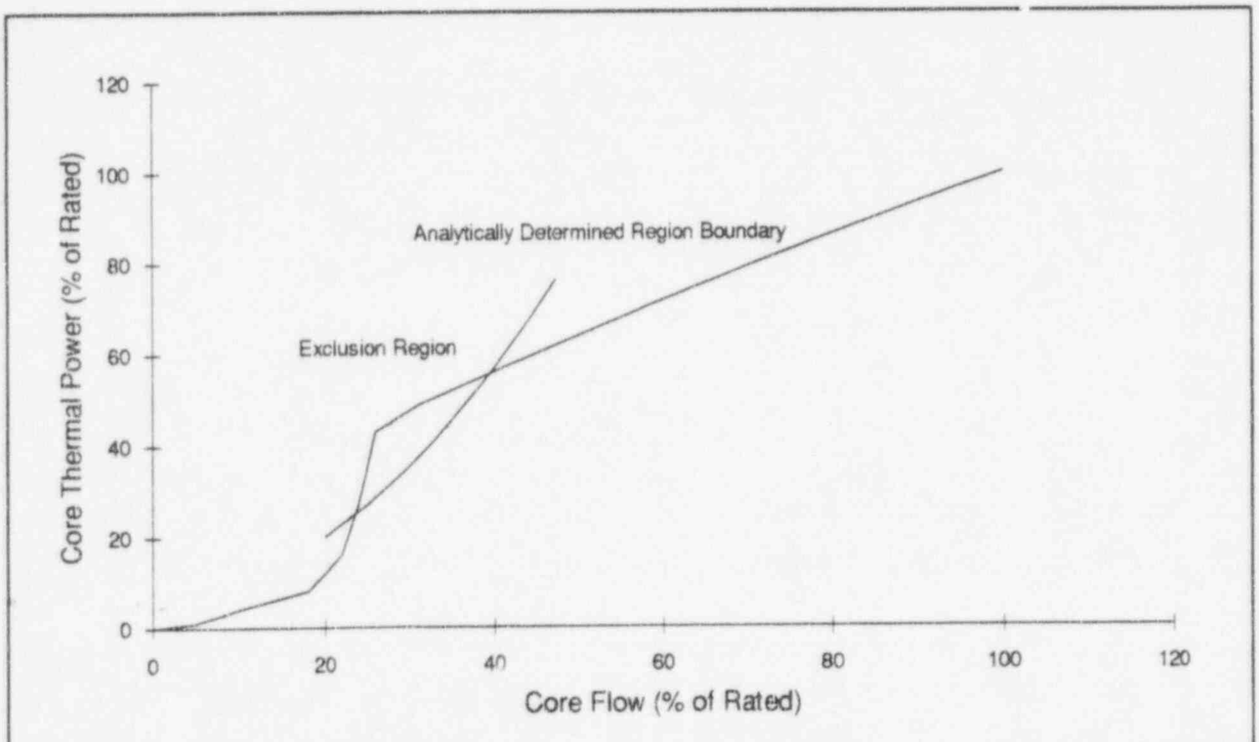
One of the solutions which demonstrates the adequacy of existing hardware is Option I-D, entitled, "Regional Exclusion with Flow-Biased APRM Neutron Flux Scram." This solution consists of two parts. The first is the creation of an Exclusion Region in the operating map for the plant (Figure 1-1). This is a region where conservative decay ratio calculations indicate that power oscillations are possible. If the plant should enter this region due to a flow reduction event, such as a recirculation pump trip or runback, or due to a power increase at low flow, the operators are instructed to promptly exit the region and initiate a manual scram if oscillations occur. As a part of the generation of the Exclusion Region, the margin to regional mode oscillations is quantified using the methodology identified in Supplement 1 to NEDO-31960[1]. As described therein (Section 5.0), there are unrealized conservatisms in the prediction of the already low likelihood of regional mode oscillations by neglecting the higher eigenvalue separation for the small core size of Monticello.

The second part of this solution is a demonstration that, even in the unlikely event of a power oscillation, an APRM flow-biased flux trip will detect and suppress the most probable mode power oscillations (core-wide mode) before the SLMCPR is reached. This demonstration uses the statistical methodology described in NEDO-32465[2]. It is conservatively applied for core-wide mode oscillations both in terms of the inputs and confidence levels used in the statistical methodology.

While the Exclusion Region and MCPR analysis are the components of the Option I-D solution which are analytically demonstrated, they are not, in and of themselves, the complete solution. Recognizing that highly skewed axial power shapes reduce margin to the onset reactor instability, an on-line stability predictor and administrative controls are being added to Monticello by the licensee. Therefore, the analytical demonstrations are part of a hierarchy of barriers that provide a high degree of assurance that fuel thermal limits cannot be approached. The barriers that must be scaled before fuel limits can be approached may be summarized as:

- Occurrence of a transient that brings the plant into the Exclusion Region (e.g., recirculation pump trip, recirculation pump runback, inadvertent control rod withdrawal or loss of feedwater heating during startup).
- Failure to leave the Exclusion Region either by increasing flow or decreasing power (It has been observed that an appreciable time lapse occurs before the system stabilizes at the new operating point and that oscillations require some time to evolve: there is adequate time for the operators to maneuver the plant out of the Exclusion Region or to scram the plant upon recognition of an oscillation.).
- Development of oscillatory power behavior outside of the expected statistical occurrence for which a RPS trip does not occur before fuel thermal limits are exceeded.

Figure 1-1. Typical Exclusion Region in Operating Map



1.4 Applicability of Option I-D to Monticello

Integral to the Option I-D approach is the assertion that regional mode oscillations have a low probability of occurrence. One feature of Monticello that assists in protecting against the occurrence of regional mode oscillations is that there are large single-phase channel pressure losses when compared to other BWR's. Such losses, in the absence of other changes in core hydraulic characteristics, are known to be stabilizing. When comparing various plant designs, differences in single phase pressure losses are mostly attributable to the fuel inlet orifices; thus, plants, such as Monticello, which have relatively small inlet orifice diameters, are expected to be more stable than those with large inlet orifice diameters (the inlet orifice diameter for Monticello is 2.15 inches as compared to 2.43 inches for most BWR 4's and 5's) and less likely to excite higher harmonic modes of reactor instability.

A second feature is that the core is relatively "small." Since the phenomenon underlying the neutronic portion of regional mode oscillations is the excitation of the higher harmonics modes of the fundamental (i.e., critical) flux shape, the occurrence of region mode oscillations requires the insertion of sufficient reactivity to overcome the inherent sub-critical multiplication of those modes (i.e., "eigenvalue separation"). The eigenvalue separation has been found to be strongly dependent on the size of the core, with smaller cores (e.g., 484 bundles) having markedly greater separation than larger cores (e.g., 764 bundles). Nevertheless, the current analysis conservatively neglects eigenvalue separation and relies wholly on the larger hydraulic losses of the inlet orifices to demonstrate a preference for the core-wide mode of oscillation.

A third feature in the application of Option I-D is that Monticello has a relatively low power density (~42 kW/l) when compared to the other plants (~49-51 kW/l) that are implementing the Option I-D solution. A lower power density translates into a lower absolute power to flow ratio in the core at the same relative state point on the power/flow operating map and provides additional stability margin.

A fourth feature in the application of Option I-D is that Monticello has an unfiltered APRM Flow Biased Flux Scram instead of a Simulated Thermal Power Monitor (STPM). The APRM neutron flux signal provides an instantaneous response to an oscillation rather than the slower fuel thermal response associated with a STPM. The assertion for a small core such as Monticello with 484 bundles is that (1) a core-wide mode oscillation will be excited long before an azimuthal (regional mode) oscillation, and (2) the APRM Flow Biased Flux Scram will suppress the oscillations before a thermal limit is reached (the MCPR limit is the most sensitive thermal limit for oscillations).

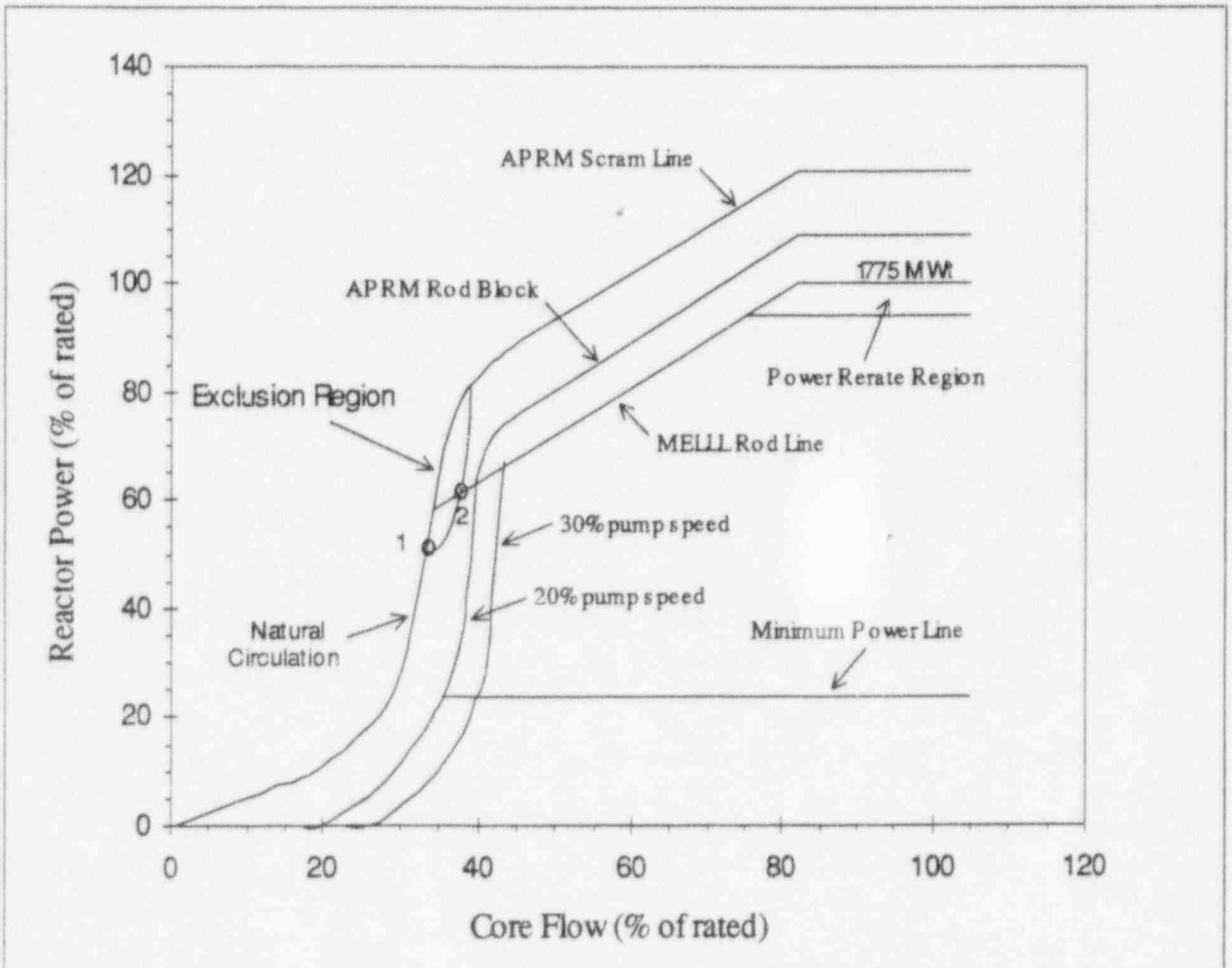
The analysis contained in this report has been performed based on power rerate conditions (1775 MWt) and bounds operation prior to rerate at 1670 MWt. Any percent power references in this document are relative to a rated power level of 1775 MWt, except where noted.

2 SUMMARY AND CONCLUSIONS

Compliance with General Design Criterion 12 is demonstrated with the Regional Exclusion with Flow-biased APRM Neutron Flux Scram Stability Solution (Option I-D) for Cycle 18 of the Monticello Nuclear Generating Plant.

The Exclusion Region for Cycle 18 of Monticello is shown in Figure 2-1. The analysis confirms that core-wide mode oscillations are the preferred mode for Monticello primarily due to the relatively small fuel inlet orifices.

Figure 2-1. Monticello Exclusion Region (Cycle 18)



Protection of the Safety Limit Minimum Critical Power Ratio (SLMCPR) is demonstrated for core-wide mode oscillations on the rated licensing procedure flow-control line in accordance with the statistical methodology defined in NEDO-32465[2]. Therefore, the flow-biased APRM neutron flux trip provides protection of the fuel SLMCPR against the preferred mode of oscillation with high statistical confidence for Cycle 18.

Results of this demonstration for Cycle 18 are expected to be applicable to future reload cycles due to the use of conservative inputs and assumptions. However, it is appropriate to confirm applicability of the specific inputs and conditions identified in Section 7 for subsequent reload designs on a cycle-by-cycle basis.

3 APPLICATION OF BWROG STABILITY LONG-TERM SOLUTION REGIONAL EXCLUSION METHODOLOGY

Section 3 describes the application of the BWROG Regional Exclusion Methodology for Monticello. This application is intended to define the power flow conditions to be avoided during normal operation. Also, the results of this analysis conservatively verify that the core-wide mode is the preferred mode for Monticello. The analysis inputs described below for the demonstration application were developed for Cycle 18. Future operating cycle reload analysis will confirm the applicability of the power flow map Exclusion Region and preference for core-wide mode oscillations to the particular characteristics of the new fuel cycle.

The algorithm used to define the Exclusion Region is based on the FABLE/BYPSS methodology and the inputs to it are as described in Section 5.2 of the BWROG methodology report[1]. Input parameters that are dependent upon cycle specific parameters, such as fuel loading, are from Cycle 18 for Monticello. As such, the Exclusion Region is specific to Cycle 18 and its validity must be confirmed for each subsequent fuel reload.

3.1 Void Coefficient

The most negative point model void-feedback parameters (nuclear void coefficient and delayed neutron data) for Cycle 18 are used. Since this coefficient is the most negative value for the cycle, it does not correspond to the other inputs to the methodology (e.g., axial power distribution) but is conservative.

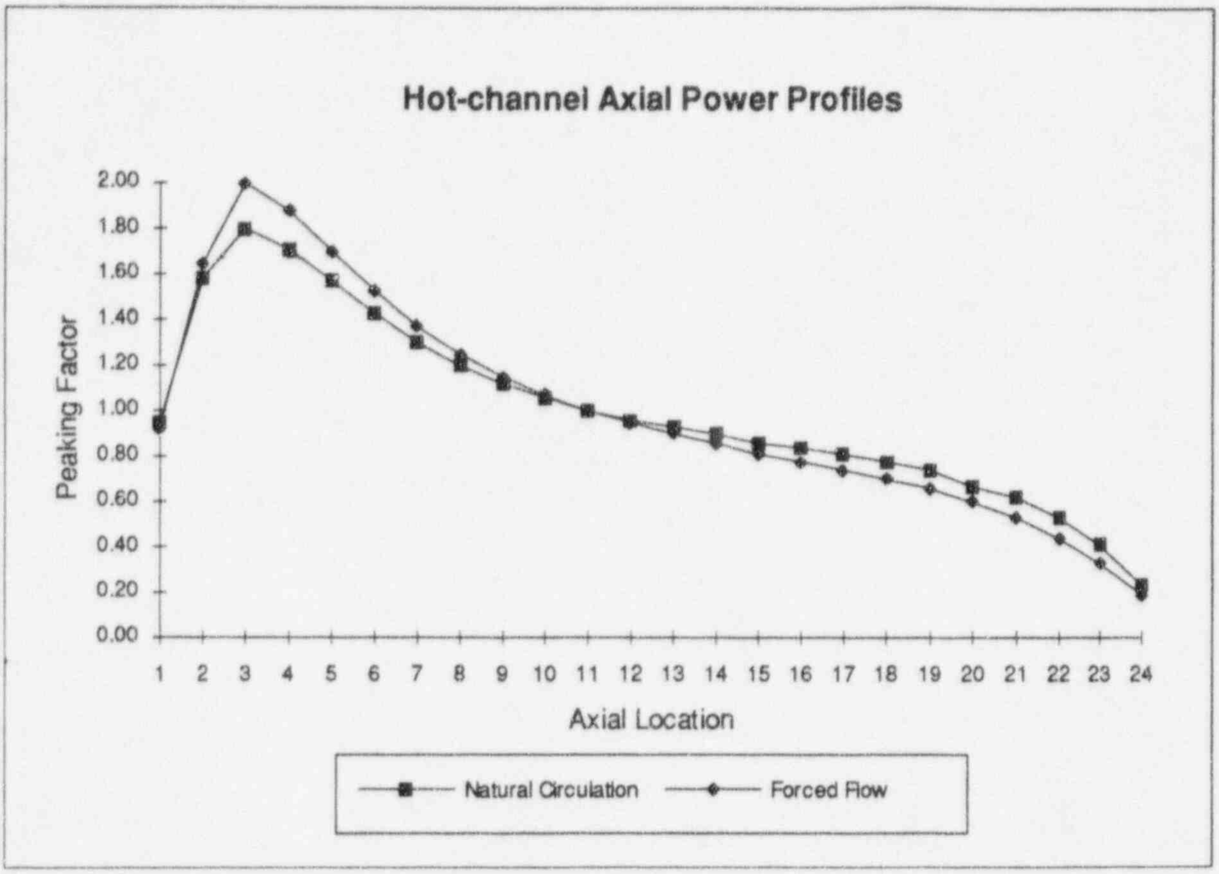
3.2 Thermal-hydraulic Data

Standard design values for Monticello, consistent with the FABLE/BYPSS qualification bases, are used in the analysis.

3.3 Hot-Channel Axial Power Distribution

Channel hydraulic stability is known to be strongly affected by the channel's axial power distribution. For the hot channels, the axial power distribution is fixed by the procedure to be peaked near the bottom of the channel, a distribution that is known to be less stable. These axial power distributions for both forced flow and natural circulation are shown in Figure 3-1. These axial profiles are consistent with those shown in Figure 5-5 of the BWROG methodology report[1]. Hot channels are identified for each hydraulic channel design in the Monticello core.

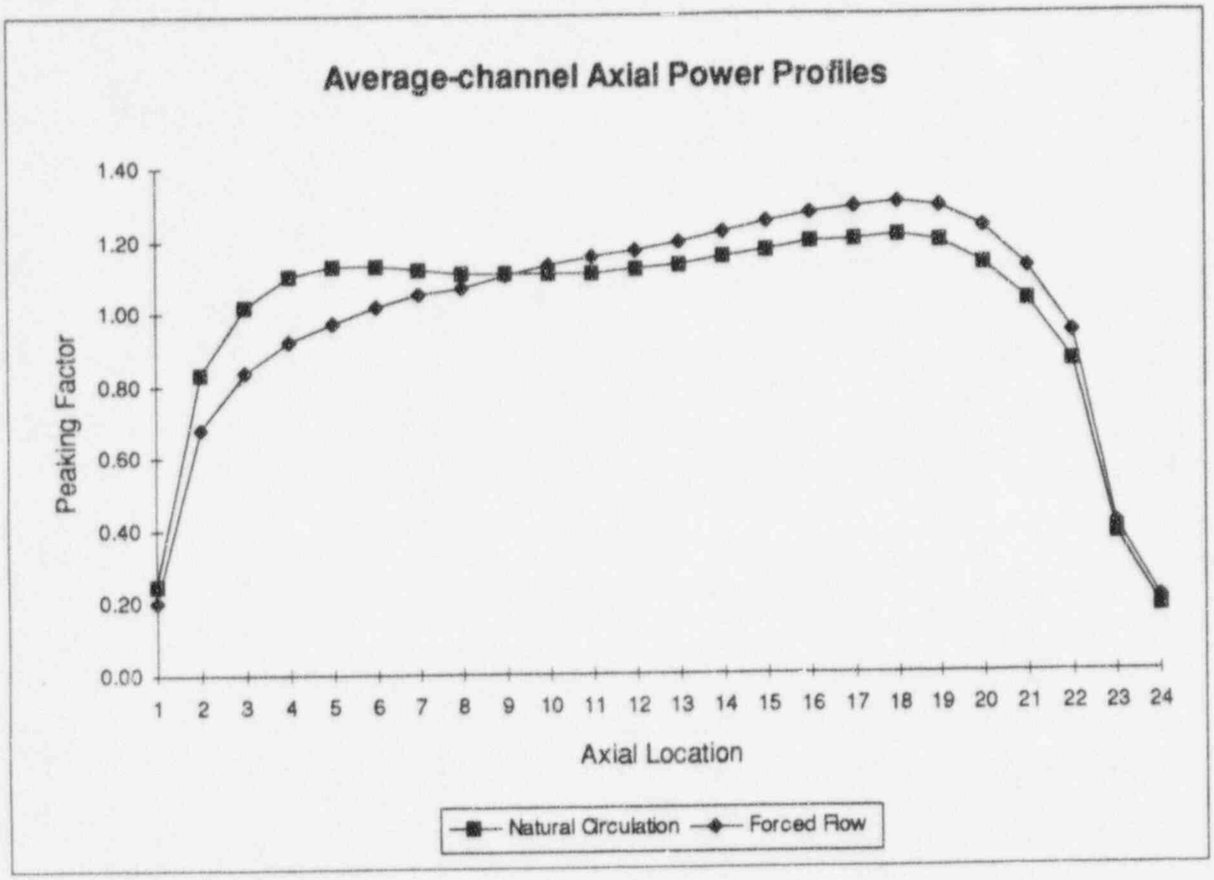
Figure 3-1



3.4 Average-Channel Axial Power Distribution

Core stability is known to be affected by the axial power distribution of the bulk of the channels in the core (all those other than the "hot channels"). In the absence of other changes, a relatively "flat" axial power distribution will be less stable than top-peaked or bottom-peaked distributions; therefore, for forced circulation conditions, the Haling End-of-Cycle 18 (EOC-18) full power and flow core-average axial power distribution is used (see Figure 3-2). For natural circulation conditions the power distribution moves strongly to the bottom of the core and use of a Haling profile characteristic of full power and flow would be too conservative; therefore, a core-average axial power distribution characteristic of natural circulation flow at the Haling EOC-18 exposure point is used. The axial power profile at the intersection of the rated licensing procedure flow-control line (RLPFCL) and the natural circulation flow line is shown in Figure 3-2.

Figure 3-2



3.5 Radial Power Distribution

The radial peaking factors for the channel grouping used in the FABLE/BYPSS analyses are based on those obtained from the GE 3D BWR Simulator Code[11]. The values chosen are from the EOC-18 Haling exposure point.

3.6 Pellet-Clad Gap Conductance

Core average pellet-clad gap conductances were determined for each fuel design using the approved fuel licensing model consistent with the FABLE/BYPSS qualification bases.

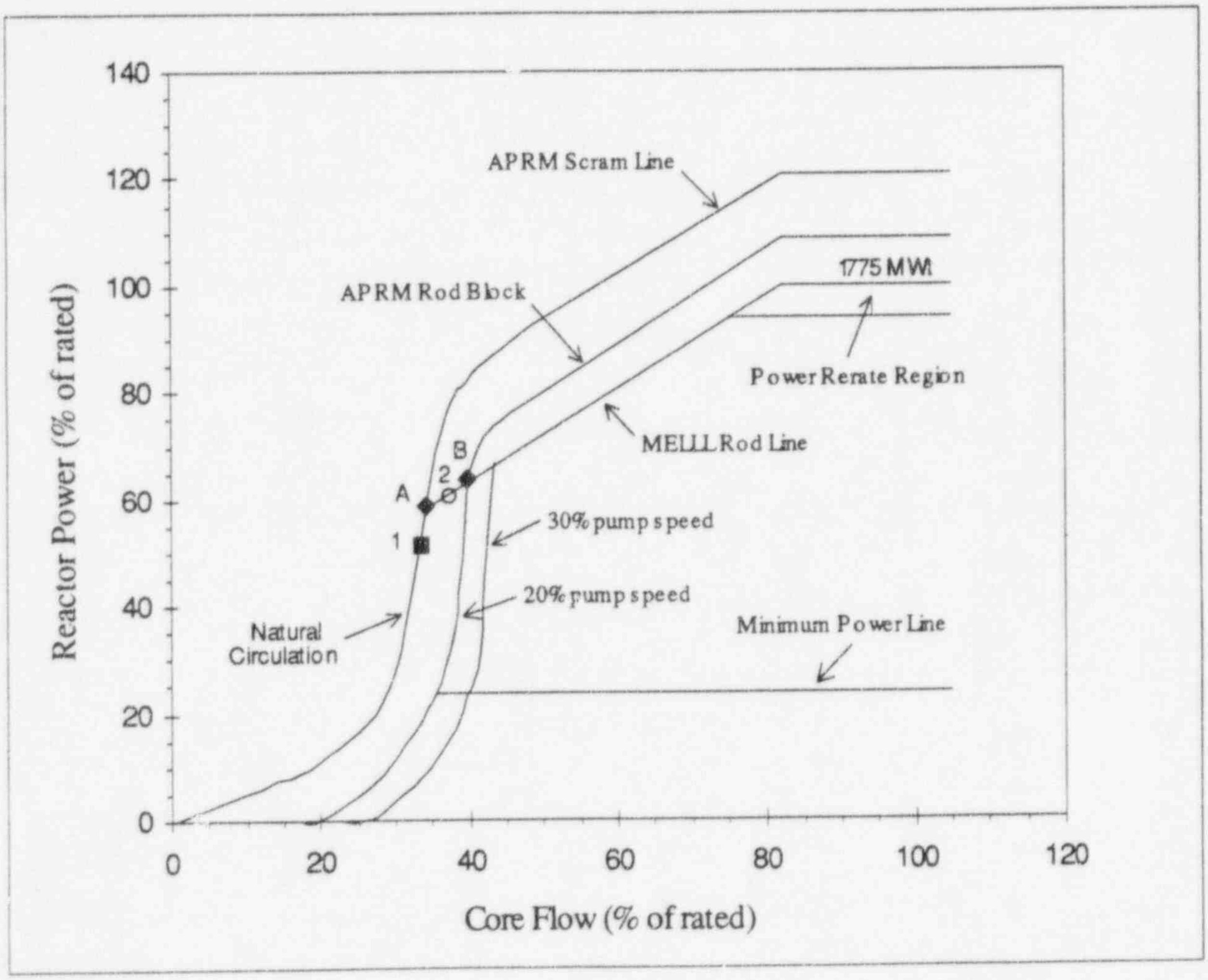
3.7 Miscellaneous Input Values

Other input values to the FABLE/BYPSS analyses, such as heat balance data, recirculation loop resistance, fuel physical parameters and material properties are standard design values for the Monticello plant. It is assumed that the nominal heat balance assumptions, such as the operation of all feedwater heaters, are valid for this model.

4 REGIONAL EXCLUSION RESULTS

Core and channel decay ratios were calculated for several power flow combinations on the operating map (see Figure 4-1) using the inputs described in Section 3. The purpose of analyzing these combinations is to determine the Exclusion Region boundary on the power flow map and, using the generic BWROG Stability Criterion Map, establish the preferred mode of oscillation and the margin to the occurrence of regional mode oscillations for Monticello.

Figure 4-1. Probe Points on Operating Map



The points calculated are provided in Table 4-1. Points A and B are along the MELLL Rod Line; points A and 1 are along the natural circulation line, with point A being at the intersection of the MELLL Rod Line and the natural circulation line. The core and channel decay ratio results of the analyzed points are tabulated in Table 4-1.

Table 4-1 Probe Points on Operating Map

Point Number	Power (%)	Flow (%)	Channel Hydraulic Decay Ratio	Core Decay Ratio	Symbol on Figure 4-2
1	52.0	34.2	0.33	0.79	1
A	58.3	34.2	0.38	0.90	A
B	63.9	39.9	0.31	0.48	B
2*	59.7	35.6	0.36	0.80	2

*To determine the 0.8 core decay ratio power/flow point on the MELLL rod line, interpolation between points A and B was used. 1775 MWt = 100% rerated.

The points shown in Figure 4-1 and provided in Table 4-1 are plotted on the Stability Criterion Map in Figure 4-2. The plotting symbols have been provided in Table 4-1 for clarification. The lines which connect the appropriate state points in Figure 4-2 are used to determine the power and flow conditions at which the stability map criterion are exactly met. The coordinates of the intersections with the stability map criterion lines are given in Table 4-2.

Figure 4-2 Coordinates of Probe Points on Stability Criterion Map

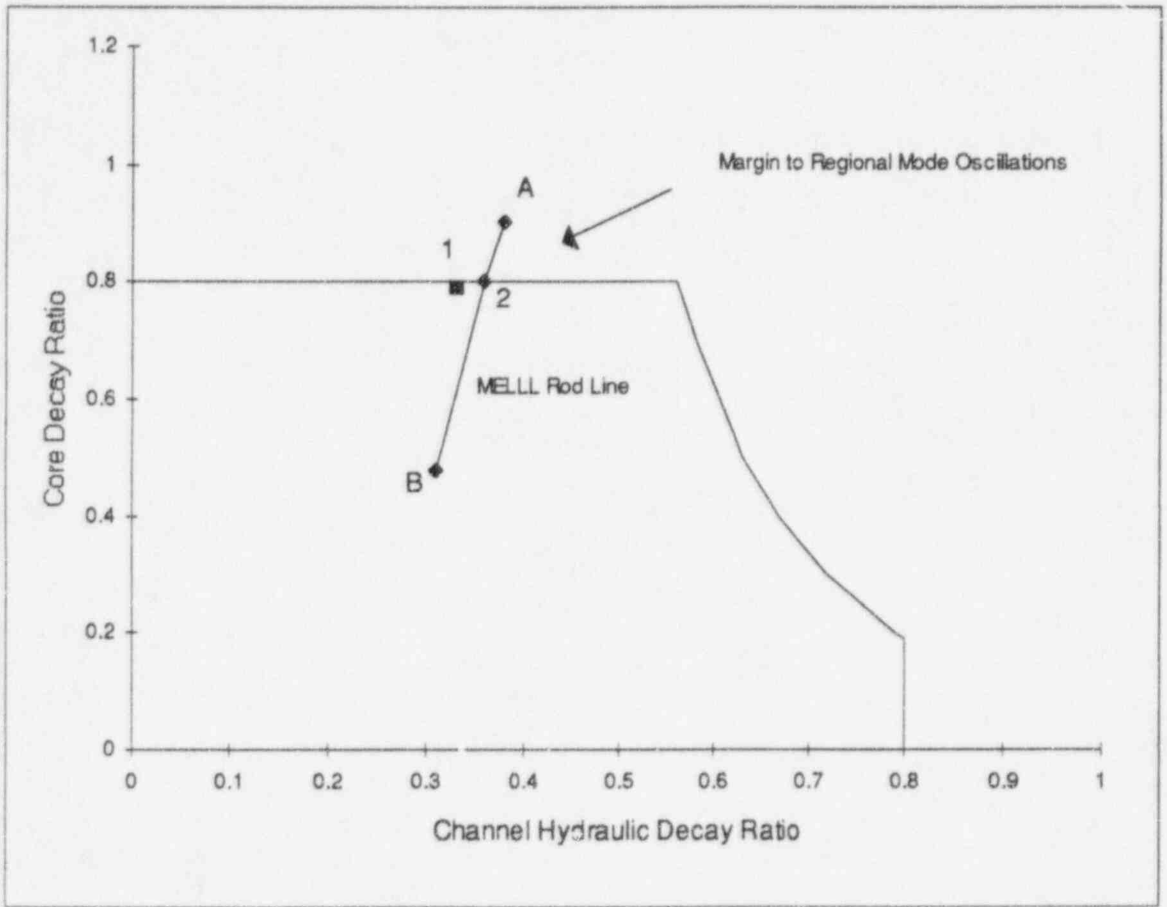


Table 4-2 Coordinates of Exclusion Region Boundary

Point #	Power (%)	Flow (%)
1	52.0	34.2
2	59.7	35.6

The coordinates of the probe points on the generic BWROG Stability Criterion Map, Figure 4-2, provide further evidence that regional mode oscillations are not probable for Monticello. It was shown in the stability solutions licensing methodology report[1] that the probability of regional mode oscillations becomes progressively smaller as channel hydraulic decay ratio is decreased, and regional mode oscillations have not been observed for channel hydraulic decay ratios less than 0.6. The largest channel hydraulic decay ratio conservatively predicted by the methodology for Monticello is 0.38 and occurs at the intersection of the natural circulation flow line and the extended operating domain MELLL Rod Line. Regional mode oscillations are not anticipated anywhere on the operating map for Monticello because of this large margin.

The points identified in Table 4-2 were then used to determine the location of the Exclusion Region boundary, which is shown in Figure 4-3. The Exclusion Region boundary for Monticello is specified by the boundary shape function equation which has been validated against previous Option I-D plant-specific region boundary calculations. The equation for the boundary is as follows:

$$P = P_1\left(\frac{P_2}{P_1}\right)^{\frac{1}{2}\left[\left(\frac{W-W_1}{W_2-W_1}\right)+\left(\frac{W-W_1}{W_2-W_1}\right)^2\right]}$$

where,

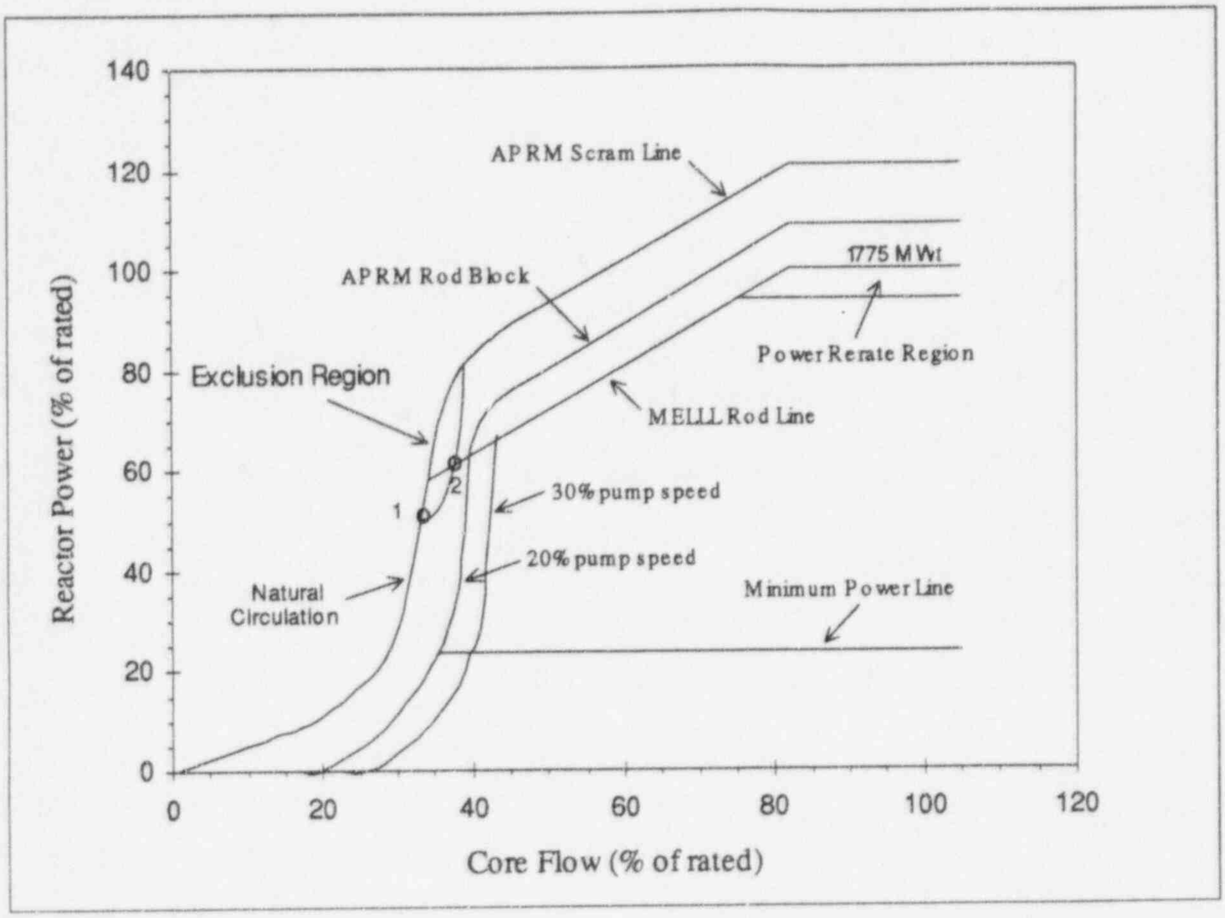
P = percent of rated power,
P_2 = percent of rated power at point 2,
P_1 = percent of rated power at point 1,
W = percent of rated core flow,
W_2 = percent of rated core flow at point 2,
W_1 = percent of rated core flow at point 1.

The range of validity of the fit is:

$34.2\% < \%\text{Flow} < 35.6\%$

Note that entry into the exclusion region above the MELLL line is operation in a non licensed part of the power-flow map.

Figure 4-3 Monticello Exclusion Region (Cycle 18)



5 APPLICATION OF BWROG STABILITY LONG-TERM SOLUTION DETECT AND SUPPRESS METHODOLOGY

5.1 LICENSING COMPLIANCE

Section 5 describes the application to Monticello Cycle 18 of the Detect and Suppress portion of stability long-term solution Option 1-D. This application demonstrates protection of the SLMCPR provided by the flow-biased APRM neutron flux trip for core-wide mode oscillations. The Detect and Suppress licensing methodology for application to Option 1-D is documented in BWROG Licensing Topical Report NEDO-32465[2]. Consistent with Monticello qualification as an Option I-D solution plant, the Regional Exclusion methodology demonstrates that core-wide is the predominate oscillation mode and, therefore, the Detect and Suppress calculation must only be performed for core-wide mode oscillations.

The Detect and Suppress methodology[2] assumes that a core-wide mode oscillation occurs, and is terminated by automatic reactor scram when the APRM oscillation magnitude reaches the flow-biased APRM flux trip. The methodology applies a statistical method, using a combination of statistical and deterministic inputs, to determine the final MCPR (FMCPR) with a high statistical confidence when control rod insertion disrupts the oscillation. The flow-biased APRM flux trip provides adequate protection as long as the FMCPR is greater than the SLMCPR.

5.2 METHODOLOGY OVERVIEW

The Detect and Suppress methodology is used to determine the FMCPR resulting from core-wide mode oscillations which are terminated by the APRM flow-biased scram. The rated flow-control line (RLPFCL) is used to define the plant conditions for application of the methodology. The methodology consists of three major components:

a. <u>Calculation of the Pre-Oscillation MCPR:</u> A Monticello Cycle 18-specific determination of the MCPR on the RLPFLC captures the margin to the SLMCPR prior to the oscillation. This is known as the initial MCPR (IMCPR). The IMCPR is calculated conservatively assuming the plant is initially operating at the MCPR operating limit (OLMCPR).

b. <u>Statistical Calculation of Peak Oscillation Magnitude:</u> A statistical evaluation of the normalized peak oscillation magnitude, Δh (defined as oscillation (peak-minimum)/average), due to an oscillation initiating on the RLPFCL captures the effect of plant characteristics, trip system definition, and setpoint values on the peak fuel bundle power oscillation magnitude. The statistical methodology considers power distributions, oscillation contours, oscillation growth rates, oscillation frequencies, trip overshoot, LPRM failures, and APRM failures. The result of the evaluation is a statistically conservative value of the peak hot bundle oscillation magnitude, $\Delta h_{95/95}$, at a 95% probability and 95% confidence level for anticipated reactor instability.

c. MCPR Performance of the Hot Bundle: A relationship between the fractional change in CPR and the hot bundle oscillation magnitude for core-wide mode oscillations captures the effect of fuel design. The relationship has been derived from 3-D TRACG analyses performed over a range of conditions and conservatively represents current Monticello loaded fuel designs.

The IMCPR and oscillation magnitude calculations are both evaluated at the RLPFCL. Additional conservatisms have been added to the methodology to streamline the reload review process. A relatively simple confirmation of the applicability of each portion of the Monticello Cycle 18 Detect and Suppress calculation is all that will be required for subsequent fuel cycles to assure with a high confidence that the RPS trip setpoints continue to provide protection of the SLMCPR for anticipated reactor instability. If the applicability of a portion of the calculation cannot be assured, then specific portions of the calculation would need to be re-performed.

Further information on application of each of the three portions of the methodology to Monticello Cycle 18 is provided in the following.

5.2.1 PRE-OSCILLATION MCPR

The IMCPR is the more limiting (lower) of the MCPR from two scenarios on the RLPFCL. The two scenarios evaluated are (1) a two recirculation pump trip from rated flow with the MCPR at the OLMCPR, and (2) steady-state operation at 45% core flow at the applicable flow-dependent OLMCPR.

5.2.1.1 Two Recirculation Pump Trip

For Monticello Cycle 18, the lowest OLMCPR is assumed to be bounded by the cycle 17 value of 1.35[13]. Flow runback analysis completed on the RLPFCL with the 3D core simulator determined that the CPR increase due to the flow runback from rated flow to natural circulation is 0.285. Therefore, the IMCPR for Condition 1 is:

$$IMCPR_1 = 1.35 + 0.285 = 1.635$$

5.2.1.2 Steady-State Operation at 45% Core Flow

For Monticello Cycle 18, The OLMCPR on the RLPFCL at 45% flow is computed from the flow-dependent MCPR limits for Monticello Cycle 18[13], assumed to be bounded by cycle 17 values resulting in:

$IMCPR_2 = 1.38$

5.2.1.3 Limiting IMCPR

The IMCPR is the more limiting (lower) of $IMCPR_1$ and $IMCPR_2$:

$IMCPR = Min[IMCPR_1, IMCPR_2] = 1.38$

5.2.2 STATISTICAL CALCULATION OF HOT BUNDLE OSCILLATION MAGNITUDE

The statistical model is described in BWROG Licensing Topical Report NEDO-32465[2]. The model calculates hot bundle oscillation magnitude, Δh, dependent on a combination of statistical inputs and deterministic plant-specific factors. The statistical model results in selection of a conservative value of the hot bundle oscillation magnitude, $\Delta h_{95/95}$, at the 95% probability with a 95% confidence level.

5.2.2.1 Statistical Inputs

Growth Rate: A review of actual instability events indicates that most BWR oscillations would be expected to have a growth rate only slightly above 1.00. For Monticello application, the growth rate is randomly selected from the probability density function with a χ^2 distribution shown in Ref. 2.

Overshoot: The trip setpoint overshoot is a measure of how much an oscillation exceeds the trip setpoint. The overshoot is the fraction of the peak-to-peak difference between two consecutive cycles which is above the setpoint, when a trip occurs. Thus, $0.0 \leq \delta \leq 1.0$; and the value of δ can be considered to be essentially random. For Monticello application, the overshoot is randomly selected from the uniform distribution shown in Ref. 2.

Oscillation Period: The statistical methodology considers a range of oscillation periods. Studies of actual instability events indicate that the expected value for the period is approximately 1.8 to 2.0 seconds. However, it is desirable to consider an oscillation frequency range between 0.7 Hz and 0.3 Hz. This corresponds to a desired period range of $1.4 \text{ sec} \leq T \leq 3.3 \text{ sec}$. For Monticello application, the oscillation period is randomly selected from the probability density function with a χ^2 distribution shown in Ref. 2.

LPRM Failures: The statistical model provides options for considering an input LPRM failure probability distribution, a fixed failure percentage, or no LPRM failures in the calculation of hot bundle oscillation magnitude. For Monticello application, a random number of LPRM failures are selected from the distribution specified in Ref. 2 which is representative of plant data on LPRM failure rates. The specific LPRMs which are defined to fail for a given trial are then randomly selected from the total Monticello LPRM population.

Oscillation Contours: The statistical model randomly selects from the specified set of oscillation contours. Monticello application uses plant-specific contours developed for core-wide mode oscillations.

5.2.2.2 Deterministic Inputs

LPRM Assignments: Option 1-D relies on the APRM flow-biased trip. LPRMs are assigned to their respective APRM channels according to the plant configuration. All non-failed LPRM signals in an APRM are used to produce an averaged power signal for comparison to the trip setpoint. Monticello is designed with 96 LPRMs, in 6 APRM channels.

Trip Setpoint: The nominal APRM trip setpoint is input as a percentage of rated power. At natural circulation, the flow-biased APRM trip is at 65.9% of rated (1775 Mwt) reactor power[14].

Radial Peaking Factor: Since only the fundamental mode from the 3-D BWR simulator is used to calculate the relative LPRM signal averages, A, there is only one hot bundle in the core-wide mode oscillation. This bundle is also the "true" hot bundle with the highest radial peaking factor. Its normalized oscillation magnitude, Δh, is the same as any other location in the core. The radial peaking factor used for Monticello is 1.44[2].

RPS Trip Logic: Monticello has a one-out-of-two, taken twice trip logic. Therefore, at least one channel from Division I ***and*** at least one channel from Division II must reach the APRM trip setpoint for the trip signal to be generated.

APRM Channel Failure: In addition to the failure of individual LPRMs, the failure of one APRM channel is considered. The model provides several options: no APRM channel failure, failure of a specified channel, failure of a randomly selected channel, and failure of the most responsive channel. For conservatism, the failure of the most responsive channel (i.e., the first channel to reach the trip setpoint) is used for Option 1-D analysis.

Delay Time: The delay time for control rod insertion to terminate oscillation growth is input to the model. The time at which the reactor trip criterion is reached plus the delay time sets the time window in which the peak hot bundle oscillation magnitude can occur. The delay time is a plant-specific input[15] consisting of the APRM response time (60 msec), the RPS processing time (50 msec), the control rod drive delay time before rod motion begins (200 msec), and the time for control rods to insert two (2) feet into the core assuming control rods insert at the minimum scram speed allowed by the plant Technical Specifications (590 msec). Even though control rod insertion two feet into the core will not shut the reactor down, it is judged to be adequate to prevent further growth of the hot bundle oscillation. Therefore, the total delay time for Monticello Cycle 18 is 900 msec.

5.2.3 MCPR PERFORMANCE OF THE HOT BUNDLE

The relationship of change in CPR as a function of oscillation magnitude has been designated as the DIVOM curve (Delta CPR over Initial CPR Vs. Oscillation Magnitude). Application to Option I-D uses the generic DIVOM curve for core-wide mode oscillations[2], which is the same as the fixed DIVOM curve previously specified for Option 1-D application. The equation of the fixed curve is [ΔCPR/IMCPR = 0.175 * $\Delta h_{95/95}$ + 0.05]. The specified fixed curve is shown in Figure 5-1.

The generic DIVOM curve for core-wide mode oscillations is reasonably conservative (but not necessarily bounding in all cases) when compared to the TRACG CPR performance data[2]. It is very conservative for application in the licensing methodology since using a nominal value for the slope of the generic DIVOM curve with the $\Delta h_{95/95}$ hot bundle oscillation magnitude would produce a FMCPR at approximately the 95/95 level.

5.3 FINAL MCPR CALCULATION

The three-parts of the Detect and Suppress methodology provides for a conservative calculation of the minimum MCPR for an anticipated stability-related oscillation. First, the initial MCPR (IMCPR) is determined by a cycle-specific evaluation at the RLPFCL. Next, the hot bundle oscillation magnitude ($\Delta h_{95/95}$) is calculated at the RLPFCL. Finally, the MCPR change (ΔCPR/IMCPR) corresponding to $\Delta h_{95/95}$ is determined. From these three elements, the final MCPR (FMCPR) can be determined:

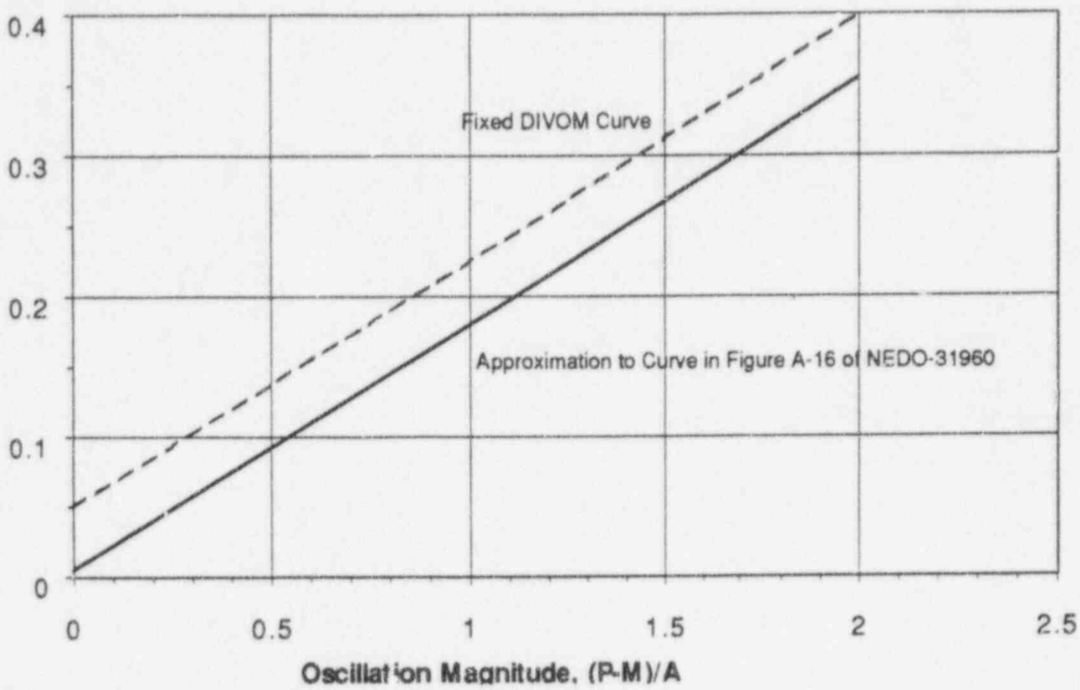
$$\text{FMCPR} = \text{IMCPR} - \text{IMCPR} * \{\Delta\text{CPR/IMCPR}\}$$

where:

{ΔCPR/IMCPR} = determined from generic DIVOM curve at the specified (P-M)/A $_{95/95}$ oscillation magnitude.

The licensing criterion is met when the FMCPR is greater than the SLMCPR. For Monticello Cycle 18, the SLMCPR is 1.07[16].

Figure 5-1. Fixed DIVOM Curve for Core Wide Mode Oscillations



6 DETECT AND SUPPRESS RESULTS

6.1 STATISTICAL MODEL CALCULATION

The statistical methodology consists of a 1000-trial Monte Carlo analysis. Based on non-parametric tolerance limits, the methodology rank orders the 1000 trials and selects the 39th trial from the end as the 95/95 value[2]. A 1000-trial statistical analysis has been calculated for Monticello Cycle 18. Table 6-1 lists the key inputs. Table 6-2 provides the highest 50 calculated values of hot bundle oscillation magnitude (Δh) and the 95/95 value ($\Delta h_{95/95} = 0.681$).

Table 6-1: Monticello Cycle 18 Inputs for Hot Bundle Oscillation Magnitude Calculation

Core Size:	484-bundle core
Trip System:	Flow-biased APRM
Trip Logic:	One-out-of two, taken twice
Oscillation Mode:	Core-wide
APRM Channel Failure:	Most Responsive APRM Channel (applied to 100.0% of all trials)
LPRM Failures:	Random (χ^2 Distribution)
Oscillation Period, T:	Random (χ^2 Distribution)
Growth Rate, Gr:	Random (χ^2 Distribution)
Overshoot, δ:	Random (Uniform Distribution)
Average Reactor Power:	51.5 % rated (100% rod line at natural circulation)
Radial Peaking Factor:	1.440
APRM Trip Level (nominal):	65.9 % rated (at natural circulation)
Total Delay Time:	900 msec. (measured from time of full trip)
Total Number of LPRMs:	96
Oscillation Contour Selection:	Random from contours: EK1B14AH2, EK1B14AH3, EK1E14AH1, EK1E14AH2, EK1M14AH2, EK1M14AH3

Table 6-2: Results of Monticello Cycle 18 Hot Bundle Oscillation Magnitude Calculation

	PERIOD (SEC)	GROWTH RATE	OVRSHT FRACT.	RANDOM LPRM FAIL	% LPRM FAIL	HOT (P-M)/A	HOT BUNDLE PEAK (% OF RATED)
MINIMUM	1.27	1	0	1	1	0.572	98.13
MAXIMUM	3.67	1.44	1	26	27.1	0.823	110.15
AVERAGE	2.04	1.1	0.49	8	8.5	0.624	100.56

6.2 FINAL MCPR CALCULATION

First, the initial MCPR (IMCPR) is determined by a cycle-specific evaluation at the RLPFCL.

$$IMCPR = 1.38$$

Next, the hot bundle oscillation magnitude ($\Delta h_{95/95}$) is calculated using the statistical methodology at the RLPFCL.

$$\Delta h_{95/95} = 0.681$$

Finally, the MCPR change ($\Delta CPR/IMCPR$) corresponding to $\Delta h_{95/95}$ is determined from the generic DIVOM curve for core-wide mode oscillations.

$$\Delta CPR/IMCPR = 0.175 * \Delta h_{95/95} + 0.05$$
$$\Delta CPR/IMCPR = 0.175 * (0.681) + 0.05 = 0.169$$

From these three elements, the final MCPR (FMCPR) can be determined:

$$FMCPR = IMCPR - IMCPR * \{\Delta CPR/IMCPR\}$$
$$FMCPR = 1.38 - 1.38 * 0.169 = 1.15$$

The licensing criterion is met when the FMCPR is greater than the SLMCPR.

$$FMCPR > SLMCPR$$
$$1.15 > 1.07$$

Since the FMCPR is greater than the SLMCPR, the APRM flow-biased trip system shows protection for core-wide mode oscillations.

7 RELOAD APPLICATION

The purpose of the reload review is to determine the applicability of previous plant-specific calculations to the current fuel cycle. The analysis documented in this report constitutes the baseline for future fuel cycle reload reviews. Table 7-1 tabulates the key parameters which must be evaluated to determine the applicability of the analysis documented herein. If some key parameters do not meet the specified criteria, the applicable portions of the analysis must be re-performed.

Table 7-1. Parameters for Reload Review Evaluation

Regional Exclusion Methodology

Description	Criteria	Base Value
There are no reactor design changes which would affect the thermal-hydraulic stability of the reactor (e.g., recirculation loop performance)	No reactor changes	--
There are no new plant operating modes (e.g., power uprated, increased load lines) which would affect the operating region of the reactor	No operating region change	--
The reload fuel design has similar stability performance as the Cycle 18 fuel design	Similar to GE11	GE11
Haling radial peaking factor increases over Cycle 18 by no more than 5%	≤ 105% of base value	1.47
Reload batch size changes by no more than 24 bundles (5% of core size) from the Cycle 18 batch size	Within ±24 bundles from base value	144 bundles
The Haling cycle exposure changes by no more than 867 MWD/ST (10% of base value) from the Cycle 18 Haling cycle exposure	Within ±867 MWD/ST from base value	8665 MWD/ST
The actual cycle exposure of the previous cycle changes by no more than 915 MWD/ST (10% of base value) from the Cycle 17 actual cycle exposure	Within ±915 MWD/ST from base value	9,151 MWD/ST

Table 7-1. Parameters for Reload Review Evaluation (continued)

Detect and Suppress Methodology

Parameter	Description	Value
OLMCPR (100/100)	MCPR Operating Limit at rated flow on the rated licensing procedure flow-control line	≥ 1.20
ΔMCPR(2RPT)	MCPR increase due to flow runback from a 2RPT	≥ 0.285
OLMCPR (100/45)	MCPR Operating Limit at 45% of rated flow on the rated licensing procedure flow-control line	≥ 1.38
#LPRMs	Number of installed LPRMs	≥ 96
APRM assignment	LPRM assignment to APRMs in 6 channels, etc.	No APRM design change
APRM trip @ NC	Flow-biased APRM trip power level (nominal value) at natural circulation	≤ 65.9% of rated (1775 Mwt) power
A @ NC	Average power level on the rated licensing procedure flow-control line at natural circulation	≥ 51.5% rated power
T_{delay}	Total delay time (60 msec APRM response time, 50 msec RPS processing time, 200 msec delay before start of control rod motion, 590 msec for 2 feet of control rod insertion)	≤ 900 msec
Fuel Design	Fuel Design which is covered by the Generic DIVOM Curve for Core-Wide Mode Oscillations	GE7, GE8, GE9, GE10, GE11, or GE12

8 REFERENCES

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